

Downscaling and geo-spatial gridding of socio-economic projections from the IPCC Special Report on Emissions Scenarios (SRES)

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Abstract

A database has been developed containing downscaled socio-economic scenarios of future population and GDP at country level and on a geo-referenced gridscale. It builds on the recent Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES), but has been created independently of that report. The SRES scenarios are derived from projected data on economic, demographic, technological and land-use changes for the 21st century in a highly aggregated form consisting of four world regions. Since analysts often need socio-economic data at higher spatial resolutions that are consistent with GCM climate scenarios, we undertook linear downscaling to 2100 of population and GDP to the country level of the aggregated SRES socio-economic data for four scenario families: A1, A2, B1, B2. Using these country-level data, we also generated geo-spatial grids at 1/4° resolution (~30 km at the equator) for population “density” (people/unit land area) and for GDP “density” (GDP/unit land area) for two time slices, 1990 and 2025. This paper provides background information for the databases, including discussion of the data sources, downscaling methodology, data omissions, discrepancies with the SRES report, problems encountered, and areas needing further work.

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1. Introduction

Modeling human societies, extrapolating current trends of socio-economic variables, and projecting changed conditions for decades into the future present fundamental problems. To a certain extent, socio-economic scenarios are, of necessity, based on assumptions that are known to be tenuous. For instance, projecting economic growth rates for century-long periods at fine scales may be impossible and discontinuous events have rarely been predicted in advance. However, tackling these problems contributes to the evaluation of societal responses to major environmental issues, including, but not exclusively, global climate change. Land-use change and ecosystem alteration are other important issues that require similar analytical tools. Furthermore, these large-scale, integrated, and highly complex problems need to be addressed at both

global and at local and regional scales for a comprehensive understanding.

The work here presents an initial attempt at downscaling socio-economic projections that are consistent with existing projections of how global climate may change in the future. We apply the SRES regional growth rates of population and gross domestic product (GDP) uniformly to each country in 9–11 regions defined by the emissions models used in SRES. The methodology is somewhat analogous to that used in applying changes derived from coarse-resolution global climate model output (e.g., temperature or precipitation), to finer scales for regional impact studies (e.g., IPCC, 2001).

Recent criticisms of the SRES report have unfortunately created confusion and misinformation about the level of regional disaggregation used in the SRES report (Castles and Henderson, 2003a). By referring to the downscaling results presented in this paper, which were done independently and were made available in draft online versions, they may have led some readers to think the SRES report *itself* was done at a country level. The

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SRES report presented its results for *four reporting regions only* (OECD, Asia, Eastern Europe + Former Soviet Union, the Rest of World (ROW)). No country level scenarios were developed or presented. Indeed, even the more disaggregated SRES emissions models only worked at the regional level. Recent replies by the SRES lead authors have sought to correct the mis-information (Nakićenović et al., 2003a, b).

Although we focus on the SRES scenarios in this study, many alternative scenarios have been generated independently of the IPCC (e.g., Hammond, 1998; GEO, 2002; De Vries et al., 1994) and these have been used in various regional impact studies (e.g., Strzepek et al., 2001). The SRES report was cognizant of many of these alternatives and those scenarios that included greenhouse gas emissions were compared to other available greenhouse gas and socio-economic projections (Nakićenović et al., 2000).

Given the century-long timeframe for this work, the resulting downscaled databases, especially that for GDP, are not expected to be robust future predictions. Rather, they are analytical exercises provided to explore a range of potential future conditions. Applications of this type of downscaled data are only in the early stages (e.g., Arnell et al., 2004; Parry et al., 2004). The country-level data may be used in global and regional (multi-country) modeling of the human aspects of climate change (emissions, impacts, vulnerability, and adaptation); the gridded data may be used as a component of sub-national studies, all with appropriate caveats.

In this paper, we provide background information about the SRES methods that are germane to the exercise and describe the downscaling methodology for the population and GDP indicators at both the country level and the geo-referenced grid scale. We highlight difficulties encountered, including lack of precise base-year agreement among the SRES models, discontinuities that arise from downscaling the population projections, very high 2100 incomes, and alternative GDP measures. Finally, we highlight these and other areas that require more sophisticated treatment so as to improve the analytical tools available for integrated assessment of global environmental change.

2. SRES storylines, regions, and models

The IPCC Third Assessment Report (TAR) published the new set of emissions scenarios, called the Special Report on Emissions Scenarios (SRES), in 2000 (Nakićenović et al., 2000). The mandate for the new scenarios originated within the IPCC in 1996. One motivation was the need for an updated emissions series over the previous IPCC “IS92” series, given the changed geopolitical landscape since 1990, such as the former Soviet Union and Eastern European political restructuring.

The final emissions results of the SRES report are available online from Columbia University’s Center for International Earth Science Information Network (CIESIN) at: http://sres.ciesin.org/final_data.html. A complete online text of the SRES report is available at <http://www.grida.no/climate/ipcc/emission/>.

The SRES scenarios span the 21st century and project emissions for the major greenhouse gases, ozone precursor gases (CO, CH₄, NO_x, NMVOC’s), and sulfate aerosol emissions, as well as land-use changes. Such emissions will drive climate change as well as atmospheric chemistry over the next century. Following their use in the IPCC TAR, the SRES framework has increasingly become a reference document for modeling the human dimensions component of impacts assessment (Gewin, 2002).

In addition, the scenarios synthesize a good deal more information than anthropogenic emissions, including the major driving forces behind human development including economic, demographic, social and technological change. These were included in SRES because all these factors play a role in energy consumption, land-use patterns and emissions. A collateral benefit is that the SRES scenarios are useful for other research purposes on sustainable development.

In the SRES report, future world and regional population and GDP growth rate changes were adopted as exogenous drivers to the emissions models. In other words, the SRES models did not each develop their own projections for these factors but rather used harmonized data for population and GDP growth to 2100, which was agreed to by a consensus process among the SRES authors. A small range of differences for the 1990 base year GDP estimates were accepted within the modeling process (Nakićenović et al., 2000).

2.1. Storylines

Four scenario “storylines” were developed and labeled, for simplicity, A1, A2, B1, B2. These storylines were the result of analyzing different viewpoints on possible future development pathways by the members of the writing team. They have been discussed at length elsewhere (Parry, 2000; Nakićenović et al., 2000) and will be described only in briefest terms here.

Briefly, *storyline A1* characterizes a market-based, technology-driven world with high economic growth rates. World GDP reaches ~\$550 trillion (in 1990 US\$) in 2100. Economic and cultural changes are characterized by strong globalization. There is a rapid global diffusion of people, ideas and technologies. Population growth is assumed to be low (~6.5 billion in 2100), because of the importance of development in bringing about the demographic transition from high to low fertility in developing countries. Low mortality is assumed to correlate with low fertility. For these and

Table 1
World population projections (billions) used by the SRES report^a

Year	UN 1998 Long range medium (B2 scenario)	IIASA 1996 Rapid transition (A1, B1 scenarios)	IIASA 1996 Slow transition (A2 scenario)
1995	5.687	5.702	5.702
2000	6.091	6.110	6.170
2005	6.491	6.480	6.665
2010	6.891	6.850	7.168
2015	7.286	7.211	7.678
2020	7.672	7.547	8.191
2025	8.039	7.838	8.715
2030	8.372	8.072	9.247
2035	8.670	8.239	9.779
2040	8.930	8.371	10.300
2045	9.159	8.456	10.800
2050	9.367	8.488	11.300
2055	9.545	8.465	11.780
2060	9.704	8.391	12.250
2065	9.841	8.275	12.710
2070	9.960	8.121	13.140
2075	10.066	7.933	13.540
2080	10.158	7.714	13.900
2085	10.239	7.466	14.220
2090	10.306	7.174	14.530
2095	10.364	6.850	14.810
2100	10.414	6.507	15.070

^a These projections were those available at the time of, and adopted by, the SRES report, 1996–1998. More recent projections by the UN and IIASA will have differences (UN, 2001; O'Neill et al., 2001).

related reasons, the scenario assumes the IIASA “rapid demographic transition” population projections (Table 1).

Storyline A2, in contrast, is a world of lower economic development (GDP reaches \$250 trillion in 2100) and weak globalization. It is more prone to clashes between cultures and ideas, and places a high priority on indigenous values. Population growth in A2 is high (15 billion by 2100) because of the reduced financial resources available to address human welfare, child and reproductive health and education. The relatively higher fertility rates in this scenario are assumed to correlate with higher mortality rates, and so this scenario employs the IIASA “slow demographic transition” population projections (Table 1). Per capita incomes are low.

Storyline B1 comes closest to a “sustainable development” future where economic growth and environmental protection are considered compatible. It too has high economic growth (GDP is projected to be \$350 trillion in 2100), although not as rapid as A1. B1 is a world where the emphasis could be on education, equity and social welfare rather than on technological growth. Environmental protection worldwide is considered a shared priority by most nations and population growth is again low (IIASA “rapid” population scenario; Table 1).

Finally, *storyline B2* is a less prosperous version of B1 with slower economic growth (GDP is projected to \$250 trillion in 2100). Regional governance is more inward looking rather than global. Cultural pluralism is strong along with environmental protection. Technological changes diffuse slowly. Population growth is considered to be medium in this scenario (10.4 billion in 2100). For this case, the SRES used the UN 1998 medium long-range projection as described in Table 1. This is the only SRES scenario using UN population data and also the only one with a stabilizing population growth projection, with replacement level fertility rates in the long-term.

2.2. SRES reporting and model regions

The data published in the SRES report are restricted to four aggregated “reporting regions:” (1) OECD countries in 1990 (OCED90); (2) reforming economies of Eastern Europe and the former Soviet Union (REF); (3) Asia; (4) the “rest of the world” (ROW), or Africa + Latin America + Middle East (ALM).¹

However, the six emissions models used in the SRES report used greater disaggregation, with regions numbering between 9 and 13. Table 2 gives the breakdown by model of regions represented. These model disaggregations are generally not the same as those used by the UN and IIASA in their population projections. In our database, we used the UN and IIASA population disaggregations for the population downscaling and the SRES model disaggregations for the GDP downscaling.

Since the SRES models generally had a different regional breakdown compared to the UN and IIASA population projections, each model had to adapt the UN and IIASA projections to their model regions, as best they could. This process introduced some small differences into the regional population totals from the SRES models as compared to the original UN and IIASA data. This source of discrepancy will be seen in comparison tables between the SRES models and the original UN and IIASA population totals.

2.3. Marker models

One of the conclusions of the SRES report was that no particular model implementation of any of the SRES storylines should be considered more ‘accurate’ than any of the other model implementations (Grübler and Nakicenovic, 2001). Accordingly, all the six SRES models implemented as many of the SRES scenarios as possible and all of the model emissions results are

¹ The notable exceptions to this four region aggregation are the $1^\circ \times 1^\circ$ grids of short-lived ‘ozone precursor’ gases (CH_4 , CO , NO_x , and NMVOC) and sulfate aerosol (SO_2) gases (<http://sres.ciesin.columbia.edu/>; Olivier et al., 1996).

Table 2
SRES model disaggregation of the four SRES reporting regions

Model	REF	OECD 1990	ASIA	ALM
Asia Pacific Integrated Model (AIM), Nat'l Inst. Env. Studies, Japan	(1)Economies in transition	(2)OECD-West, (3)USA, (4)Oceania, (5)Japan	(6)S.E. Asia, (7)Centrally planned Asia (CPA)	(8)Middle East, (9)Africa, (10)Latin America
Atmospheric Stabilization Framework Model (ASF), ICF Consulting, USA	(1)Centrally planned Europe	(2)OECD-West, (3)USA, (4)OECD-Asia Pacific	(5)S.E. Asia, (6)CPA	(7)Middle East, (8)Africa, (9)Latin America
Integrated Model to Assess the Greenhouse Effect (IMAGE), Nat'l Inst. Public Health & Env. Hygiene, Netherlands	(1)FSU, (2)Eastern Europe	(3)OECD-Europe, (4)Canada, (5)USA, (6)Oceania, (7)Japan	(8)E. Asia, (9)S. Asia, (10)CPA	(11)Middle East, (12)Africa, (13)Latin America
Model for Energy Supply Strategy Alternatives & Gen'l Env. Impact (MESSAGE), Int'l Inst. Applied Systems Analysis, IIASA, Austria	(1)FSU, (2)Eastern Europe	(3)Western Europe, (4)N. America, (5)Pacific OECD	(6)P. Asia, (7)S. Asia, (8)CPA	(9)ME + N. Africa, (10)SSA, (11)Latin America
Multi-regional Approach Resource & Industry Allocation (MARIA), Sci. U. Tokyo, Japan	(1)FSU, (2)Eastern Europe	(3)Other OECD, (4)N. America, (5)Japan	(6)ASEAN & other Asia, (7)S. Asia, (8)China	(9)ALM & Others
Mini Climate Assessment Model (MiniCAM), Pac. NW Nat'l Lab., USA	(1)Centrally Planned Europe	(2)OECD-Europe, (3)Canada, (4)USA, (5)Oceania, (6)Japan	(7)S.E. Asia, (8)CPA	(9)Middle East, (10)Africa, (11)Latin America

recommended by the report to be treated as of equal standing (Nakićenović et al., 2000).

Nevertheless, for presentational purposes, as a way of simplifying the findings, one model for each scenario family was designated a 'marker' model. This meant that model's results for a particular scenario were considered to be a good representative for the family of runs for that scenario. For the A1 scenario, the marker model was the AIM model (Table 2; Morita et al., 1994). For the A2 scenario, the marker model was the ASF model (Pepper et al., 1992, 1998). For the B1 scenario, the marker model was the IMAGE model (Alcamo et al., 1998; De Vries et al., 1994, 1999, 2000). For the B2 scenario, the marker model was the MESSAGE model (Messner and Strubegger, 1995; Riahi and Roehrl, 2000; Roehrl and Riahi, 2000). In addition to these marker models, two other emissions models were used in the SRES report: the MiniCAM model (Edmonds et al., 1996) and the MARIA model (Mori and Takahashi, 1999).

For our database, the distinction of marker models mainly applies to the GDP downscalings because the population projections are essentially independent of SRES, as generated by the UN and IIASA. However,

for the GDP projections, the exact quantifications are model-specific, within a range agreeing with the overall SRES harmonization for GDP growth rates. In order to simplify the database, we have limited the GDP projection data to the marker model for each of the four scenario families.

3. Downscaling population scenarios

We downscaled both the aggregated population and GDP data used in the SRES report to the country level out to 2100, using a simple linear downscaling method. This method is sometimes employed by demographers needing state and local population projections that are consistent with larger regional or national projections (see, e.g., Smith et al., 2001). Each country's annual growth rate for population or GDP, at any year, was set equal to the regional growth rate within which each country resides. This method is mathematically equivalent to keeping the fractional share of each country's population or GDP, relative to the regional population or GDP, constant, at the base year value, for the duration of the forecast period (Smith et al., 2001).

The results of the population downscaling are available at <http://sres.ciesin.columbia.edu/tgcia>.²

3.1. Population base year

The base years of the UN, IIASA, and SRES population data are slightly different. The base year for data in the SRES report was 1990. The base year for population projections available to SRES from the UN and IIASA was 1995, so a country-level population list for 1990 needed to be appended (Table 3). 1990 population estimates for 184 countries were obtained from the internet-accessible UN Common Statistics Database, located at: <http://unstats.un.org/>. The data were accessed in April 2002.

3.2. B2 population downscaling

For three of the four SRES storylines (A1, A2, B1), the 1990 country-level population estimates were projected forward to 2100, using the aggregated regional projections from IIASA. For the B2 scenario, the projected country dataset only had to be generated after the year 2050, because this scenario used the UN 1998 long range population projection that extends the shorter-term 2050 projection that the UN undertakes at the country level (Table 3) (UN, 1998). To get beyond 2050, however, the downscaling procedure had to be applied between 2055 and 2100.

For the B2 scenario, we apply the regional population growth rate (in percent/year), uniformly, to each country that lies within the more aggregated UN regions from the UN 1998 long range projection. The official UN version projects the population for eight regions of the world: Africa, Asia (minus India and China), India, China, Europe, Latin America, Northern America, Oceania. However, the UN also prepared an ‘unofficial’ long range projection specifically tailored for the IPCC SRES report for 11 regions of the world: North America, Western Europe, Pacific OECD, Central and Eastern Europe, Newly independent states of the former Soviet Union, Centrally planned Asia and China, South Asia, Other Pacific Asia, Middle East and North Africa, Latin America and the Caribbean, Sub-Saharan Africa. In our database, B2 population countries were grouped according the 11 regions corresponding to the ‘unofficial’ version.³

²We have not included population data for 44 small countries, with populations less than 150,000, because these were not readily available from UN data sources in *electronic form*. Many small island nations vulnerable to sea-level rise are in this category, so that climate impacts researchers will eventually need such data. This gap will be corrected with future work.

³Thomas Buettner of the UN Population Division, assisted the SRES report by creating this 11 region version of the 1998 UN Long Range Medium Projection. The method involved reallocating the

We explain the quantitative procedure, using Angola as an example. Angola falls within the tailored UN projected region Sub-Saharan Africa (SSA). Angola’s population projection from 1995 to 2050 is supplied by the UN 1996 Revision (UN, 1998). The SSA annual regional population growth rate between 2050 and 2055 is calculated using the following formula:

$$r_{\text{SSA}}(2050 - 55) = \frac{\log_e[P_{\text{SSA}}(2055)/P_{\text{SSA}}(2050)]}{5} \quad (1)$$

Here, $P_{\text{SSA}}(2055)$ and $P_{\text{SSA}}(2050)$ are the regional SSA population totals from the UN for years 2055 and 2050, respectively. The log formula accounts for the fact that the annual growth rates are applied to a continuously changing population base.

Then, starting with Angola’s population in 2050, and using the above rate, Angola’s population in 2055 is projected as

$$P_{\text{Angola}}(2055) = P_{\text{Angola}}(2050) \exp[r_{\text{SSA}}(2050 - 55)5]. \quad (2)$$

Angola’s population in 2060 is projected using the same formula, but substituting the appropriate rate and the estimated population for 2055 on the right-hand-side of (2), and so forth. We followed this procedure for the entire country-level list in the base year.

Eqs. (1) and (2), applied together, constitute a linear scaling of the country population changes with the regional population changes. Since the rates are applied uniformly to each country within a region, the method is linear with respect to regional totals. This means that if we begin with a 1990 country population list that sums to the exact 1990 SRES regional total, the agreement with the regional totals will remain exact for the remainder of the downscaling period. Or, if the base year country population sums to $\pm 1\%$ of the SRES regional total, this base year difference will be exactly preserved at each time step for the remainder of the downscaling period.⁴

However, when the country lists are subsequently summed to the larger four SRES-reporting regions (Table 2), the linearity is not preserved because of the changing contributing weights of each of our regions to the SRES-reporting regions. This feature will be seen in the accompanying comparison tables, which show varying differences between our totals and the published

(footnote continued)

original UN projection data among the new 11 regions using splitting factors based on the country-level data from the 1996 Revision. After 2050 the splitting factors were extrapolated linearly to 2100. The PAO (Japan, New Zealand, Australia) region in the 11 regions is poorly constrained by the UN Long Range regions however and its reallocated population shows a larger decline than expected based on typical Japan projections with replacement level fertility.

⁴Depending on the source for the base year country-level population (or GDP) data, regional totals may not agree exactly with regional totals from SRES.

Table 3
Features of population projections by UN, IIASA, World Bank and USCB^a

	United States Census Bureau (USCB) 1996	World Bank (WB) 1996	United Nations (UN) Revision 1996	UN Long Range 1998	IIASA 1996
Base year for projection	1995	1995	1995	1995	1995
Forecast period	2050	2150	2050	2150	2100
No. of regions	Country-level	Country-level	Country-level	9	13
No. of variants	1	1	3	5	27+
Fertility variants	1	1	3	5	3
Long-range fertility (central case)	Below 2.1	2.1	2.1	2.1	1.9
Mortality variants	1	1	1	1	3
Migration variants	1	1	1	1	3
Migration cutoff year	?	2025	2025	2025	2100? (central)
2050 population (central case)	9.4	9.2	9.4	9.4	9.9
2100 population (central case)	—	10.32	—	10.4	10.35

With respect to the most recent 2000 UN Revision (UN, 2001), world population reached 6.1 billion in mid 2000 and is currently growing at a rate of 1.2 per cent annually, implying a net addition of 77 million people per year. By 2050, world population in the 2000 projection is expected to be between 7.9 billion (low variant) and 10.9 billion (high variant), with the medium variant producing 9.3 billion people.

^aThese features applied at the time of the SRES report, 1996–1998 (Gaffin, 1998). Some characteristics may have changed in more recent projections (UN, 2001; O'Neill et al., 2001).

four SRES-reporting region totals. The variance is not large, however, and is usually at most a few percent.

The method above is mathematically identical to keeping the ratio (or fraction) of a country's population to the regional population, constant over time. In other words, if a country starts off at $x\%$ of some regional total, it remains $x\%$ for the duration of the downscaling period. This can be understood by noting that if the ratio of a country population to a regional population remains constant over time, the country population will scale linearly with the regional population. If it scales linearly with the regional population, the country and region will have the same growth rates.

3.3. A1, B1 and A2 population downscaling

The SRES A1–B1 and A2 population scenarios for world regions were adopted in 2000 from population projections realized at IIASA in 1996 and published in Lutz (1996). The IPCC SRES A1 and B1 scenarios both used the same IIASA “rapid” fertility transition projection, which assumes low fertility and low mortality rates (Tables 1 and 3). The SRES A2 scenario used a corresponding IIASA “slow” fertility transition projection (high fertility and high mortality rates) (Tables 1 and 3).

Both IIASA low and high projections are done for 13 world regions, which are: North Africa, Sub-Saharan Africa, China and Centrally Planned Asia, Pacific Asia, Pacific OECD, Central Asia, Middle East, South Asia, Eastern Europe, European part of the former Soviet

Union, Western Europe, Latin America and North America. Detailed scenario description and results for those regions are available at: <http://www.iiasa.ac.at/Research/POP/IPCC/index.html>.

The downscaling from region to country level of the IIASA scenarios is based on the calculation of the fractional shares of each country into regions according to the year 2000 country population estimates and projections for 1990–2050, from the United Nations Population Division (UN, 2002). For each SRES population scenario, the United Nations variant that was the closest to the SRES scenario was chosen as the starting point for the population downscaling. For scenario A2, the United Nations 2000 high variant was used. According to this variant, the world population in 2050 will be 10.9 billions, whereas the A2 scenario gives a population of 11.3 billion in 2050. For scenarios A1 and B1 the United Nations medium variant was chosen: according to this variant, the world population in 2050 will be 9.3 billion, whereas the SRES A1/B1 scenarios estimated that population will be 8.7 billion in 2050.

The United Nations country age-specific populations were allocated into the 11 IIASA SRES regions (originally, there were 13 regions in the IIASA projections, but the former Soviet Union and Central Asia are brought together as well as Northern America and Middle East). Then, a fractional share was calculated for each age group (5-year age groups from 0 to 100+), for each country, from the total of the regional age structure, as reconstituted from the United Nations 2000 data in 5-year periods from 1990 to 2050. These

fractional shares were then applied to the age structure of the population of the region in scenario A1–B1 and A2 from 1990 to 2050. After 2050, the shares of each country (by age groups) were kept constant at the 2050 level and applied to the regional population from 2050 to 2100.

The results of this A1/B1 and A2 population downscaling are available at: <http://sres.ciesin.columbia.edu/tgcia>.

3.4. Population downscaling discontinuities

Artifacts arise with the present downscaling procedure for the four scenarios. The problems occur because of the post-2050 transition to the uniform growth rate method. If a country is projected by the UN Revision to have a declining (or growing) population at 2050 but falls within a larger region that has a growing (or declining) population after 2050, a discontinuity will occur. For example, Cuba and Barbados are problematic in this regard. Results such as these cannot be used. Other countries may have a slower or faster projected growth rate at 2050 than the regional projection. In these cases, the population slope for such countries will show a discontinuity, post-2050.

If we attempt to remove these discontinuities on a case-by-case basis, such as by using additional country-specific information, or even deleting them from the database altogether, then the regional totals will develop additional discrepancies with those in the SRES report. If problematic results for specific countries are to be deleted, this will require relaxing constraints on regional consistency with the SRES report. Removing such discrepancies will require more sophisticated treatments.

Alternative methods do exist for downscaling regional population projections to smaller locales (e.g., Gabbour, 1993; Pittenger, 1976, 1980; Smith et al., 2001). Two other extrapolation methods used by state and local demographers make use of recent historical data to estimate current *trends* in fractional shares and then to hold these *trends* constant over the forecast period (Gabbour, 1993; Pittenger, 1976, 1980).

In the first alternative, the trend in fractional share of regional population *size* is kept constant (Gabbour, 1993). In the second alternative, the trend in fractional share of the regional population *growth rate* is kept constant (Pittenger, 1976; Smith et al., 2001). Such methods could be applied to the population downscalings performed in this paper by calculating 2050 trends in shares of population size and growth using the UN country projections for 2045–2050, and then holding these trends constant beyond 2050. It is possible that these alternative methods might weaken or reduce the discontinuities in population change that we observe with the constant fractional shares method, although this will require further investigation. A disadvantage,

which may preclude their use for further development of the current database, is that such extrapolations may cause other difficulties if used for long timeframes beyond 2050 and out to 2100. One problem is that a declining local fractional share could lead to negative population sizes if extrapolated for sufficiently long periods. Other interpretation problems with declining fractional shares also arise when countries are embedded within growing population regions (Smith et al., 2001). We are exploring the use of such alternative downscaling approaches in current work.

4. Downscaling GDP projections

Along with population growth, economic growth rates were a second, exogenous, assumption incorporated within the four IPCC SRES scenario families. As explained in the SRES report (see especially Sections 4.2 and 4.3), economic growth rates were assumed to be “very high” for the A1 family, “medium” for the A2 family, “high” for the B1 family and “medium” for the B2 family. Quantitatively, these assumptions translated into World GDP for 2100 of between 522 and 550 trillion US1990\$ (aggregated total based on market exchange rates)/year for the A1 family, 197–249 trillion US1990\$/year for the A2 family, 328–350 trillion US1990\$/year for the B1 family and 199–255 trillion US1990\$/year for the B2 family. The corresponding per capita GDP growth rates depend on the corresponding regional population data used in the SRES report.

4.1. GDP base year issues

The 1990 base year GDP data were downloaded from a national accounts database available from the UN Statistics Division. The data were accessed in May 2002 at: <http://unstats.un.org>. From this database, we originally selected the series titled: “GDP at market prices, US\$, current prices (for 1990) (UN estimates).” The UN definitions for market and current prices are given in the footnotes below.^{5,6} However, for reasons that are probably related to the complex economic restructuring

⁵“Market prices”—The actual price agreed upon by the transactors. In the absence of market transactions, valuation is made according to costs incurred (non-market services produced by government) or by reference to market prices for analogous goods or services (services of owner-occupied dwellings) (SNA, 1993).

⁶“Current prices”—A fundamental principle underlying the measurement of gross value added, and hence GDP, is that output and intermediate consumption must be valued at the prices current at the time the production takes place. This implies that goods withdrawn from inventories by producers must be valued at the prices prevailing at the times the goods are withdrawn and consumption of fixed capital in the System is calculated on the basis of the estimated opportunity costs of using the assets at the time they are used, as distinct from the prices at which the assets were acquired (SNA, 1993).

occurring at that time, the GDP data from this source for Eastern Europe and the former Soviet Union (which together comprise the REF SRES region) are significantly too high compared to the SRES REF estimate (N. Nakicenovic, pers. comm.).

To remedy this discrepancy, we downloaded from the same UN database a second GDP series list entitled: “GDP at market prices, current US\$ (for 1990) (World Bank estimates)”. These data derive from the World Bank’s Development Indicator Reports (World Bank, 2000; WRI, 1997). When summing these data, we find it shows a much closer agreement with SRES for the REF countries. However, the World Bank country list is shorter than the UN’s list. As an interim solution, in the interests of developing as global a database as possible, we have decided to use the World Bank estimates for as many countries as they provide, and especially for the REF countries. For missing countries in other regions, we use the UN estimates.⁷

4.2. Downscaling methods

The downscaling of the SRES GDP projections for individual countries was developed using the same regional growth rate method applied to the population data, and as given by Eqs. (3) and (4). In these equations, Angola is again used as an example. As with population, SRES regional GDP growth rates were calculated from the marker model regional data and applied uniformly to each country that fell within the SRES-defined regions:

$$r_{\text{SSA}}(1990 - 2000) = \frac{\log_e[\text{GDP}(2000)/\text{GDP}(1990)]}{10}, \quad (3)$$

$$\text{GDP}_{\text{Angola}}(1995) = \text{GDP}_{\text{Angola}}(1990) \times \text{Exp}[r_{\text{SSA}}(1990 - 2000)5] \quad (4)$$

A key difference between the application of this procedure to GDP and population is that uniform GDP growth rates were necessarily applied starting in the base year of 1990. With population, uniform growth rates were applied only after 2050. (Prior to that, UN Revision population data were available to simulate near-term country population growth rates changes over time.) Therefore, our GDP downscaling introduces inaccurate national GDP growth rates in the near term, when compared to actual near-term data for countries, because current national GDP growth rates are obviously not uniform within regions.

⁷We consulted the “Penn World Tables,” (<http://datacentre.chass.utoronto.ca/pwt/pwt.html>). Initial experience with this database indicates its country list is limited for our purposes, including only 152 countries, whereas the World Bank and UN datasets allow us to form a list of over 180 countries.

Our results for the GDP downscaling are presented online at: <http://sres.ciesin.columbia.edu/tgcia>.

4.3. Methodological issues

4.3.1. GDP versus PPP measures of economic development

The GDP totals above were expressed in terms of 1990 US\$, where the aggregation between countries for 1990 was done using 1990 market exchange rates for individual currencies. The implications of using market exchange rate (MER) versus purchasing power parity (PPP), for the purposes of aggregating country GDP data to a regional level, as well as alternative measures of economic development, were explored in the SRES report (Nakicenovic et al., 2000). A discussion is now ongoing regarding whether exclusive reliance on one or the other measure would significantly change greenhouse gas emission projections from energy models (see Nakicenovic et al., 2003a, b; Castles and Henderson, 2003b, c).

Some users may prefer one GDP measure to another for different impact analyses. The disaggregated GDP data supplied to the authors from the set of SRES marker models were more readily available in market exchange rates, so the initial downscaling of GDP to the country level was first attempted using the MER data. While the current database provides the MER measure only, we are exploring the possibility of providing a PPP version as well.

4.3.2. High 2100 GDP per capita values

One finding of the database development exercise is that the regional growth rate methodology can produce very high 2100 per capita incomes. We highlight below some examples of anomalous values that results from the downscaling. However, we wish to avoid setting “acceptability” criteria to screen the results, because values that appear to be “acceptable” or “unacceptable” to us may be judged differently by others. We leave the development of such criteria to the individual user.

High 2100 values typically occur for countries with high 1990 incomes that also happen to lie within high SRES GDP growth rate regions. Examples of countries for which this was particularly severe include the following: (1) Singapore, (2) Hong Kong, (3) French Polynesia, (4) New Caledonia, (5) Brunei Darussalam, (6) Reunion, (7) Republic of Korea, (8) Gabon, (9) Mauritius. What are, no doubt, extremely high per capita incomes in 2100 occur. While we would prefer not to list such GDP values for these countries, excluding them from the database would introduce artificial regional discrepancies when compared to the SRES. A disclaimer is included in the on-line presentation that states, in addition to the nine countries listed above,

“...other countries might have to be excluded for similar, if not as extreme, reasons...”.

Other countries that have high 2100 per capita GDP values, and that for the B1 scenario, in particular, surpass that of the US in 2100 include: Germany, Italy, France and Japan among the OECD90 countries; the Russian Federation and the Baltic States (Estonia, Latvia and Lithuania) among the countries in transition; the Republic of (South) Korea, the Democratic People's republic of (North) Korea, Malaysia, Singapore and Hong Kong among Asian countries; and South Africa, Libya, Algeria, Tunisia, Saudi Arabia, Israel, Turkey and Argentina among the 'Africa, Latin America and the Middle East' group of countries (Castles and Henderson, 2003a).

There are several related reasons why some countries display potentially problematic per capita GDP growth. In some cases (e.g., the Asian and developing countries cited above), countries with relatively more affluent economies (i.e., *relative* to other countries in the region) and relatively smaller and slower-growing populations) lie within regions with rapidly increasing GDP SRES growth rates. In other cases (e.g., the OECD90, Eastern European and former Soviet Union countries cited above), the projected long-term declines in population for the B1 (and A1) scenarios play an important role in creating the high 2100 per capita income GDP levels for these countries. Moreover, in contrast, the US population between 1990 and 2100 is projected to nearly double to ~460 million, and this increase also plays a role in diluting US per capita incomes relative to other countries experiencing less rapid population increases and, or, declines.

More generally, these high incomes found in some countries and in some scenarios are the consequence of applying such a simple and coarse regional growth rate methodology to individual countries. Clearly, more sophisticated and disaggregated algorithms are needed. Had the models in the SRES report been equipped for higher levels of disaggregation, the models would have adjusted the specific GDP growth rates by country, so that the more affluent economies in very poor regions (e.g., South Africa) would not experience the same rates of development as neighboring poor countries in Sub-Saharan Africa that are in the early phases of industrialization.

Another possible method would be to use the logic of the storylines for the downscaling. For example, country-level GDP growth rates could be linked to GDP per capita levels, as was done for the four different storylines on the level of global regions (Nakićenović et al., 2000). Then, a number of different calibrations could have been applied that yield the same SRES

regional GDP levels, but with different country development paths.

5. Geo-spatially referenced grids for population and GDP

5.1. Description of the gridded population of the world (GPW) map

Demographic information, including projections, is often provided on a national basis, but global environmental and other cross-disciplinary studies increasingly require data that are referenced by geographic coordinates, such as latitude and longitude, rather than by political or administrative units. The potential utility of such geo-spatial data was a motivation behind development of the Gridded Population of the World (GPW) map (CIESIN et al., 2000). In the GPW data set, the distribution of human population has been converted from national and sub-national units to a series of geo-referenced quadrilateral grids. Version 2 of GPW provides estimates of the population of the world in 1990 and 1995. A full description of GPW can be found at: <http://sedac.ciesin.org/plue/gpw>. Fig. 1 (top) displays the 1990 GPW, using the same UN 1990 country-level population estimates that are in our database.

Using the country-level population projections from the first part of this paper, it is a simple matter to 'project' GPW forward in time. Fig. 1 (bottom) displays the 2025 projection of GPW, using the B2 scenario country-level population projection. For this projection, the year 2025 projected population of each country replaces the 1990 estimate.

Although the country-level populations change, the fractional distribution of population at each grid cell is the same as the 1990 GPW, sub-nationally. This simplification may be dealt with in further revisions by including additional data on sub-national population projections. For a near-term projection, such as 2025, a number of sub-national projections are available. For example, the US Census Bureau produces state-level population projections out to 2025 (US Census Bureau, 2002).

Despite the static sub-national spatial assumptions, there are, of course, significant international redistributions of population density implicit in the 2025 projection. One source is the varying international fertility and mortality rates, which lead to differential population growth and decline rates in the projection. A second source is due to migration. Within-country migration, while potentially important in many nations, is not included in the scope of this study. The UN 1996 Revision, upon which the B2 scenario is based, incorporates international migration rate assumptions out to 2025 (Table 3). For countries with a long history

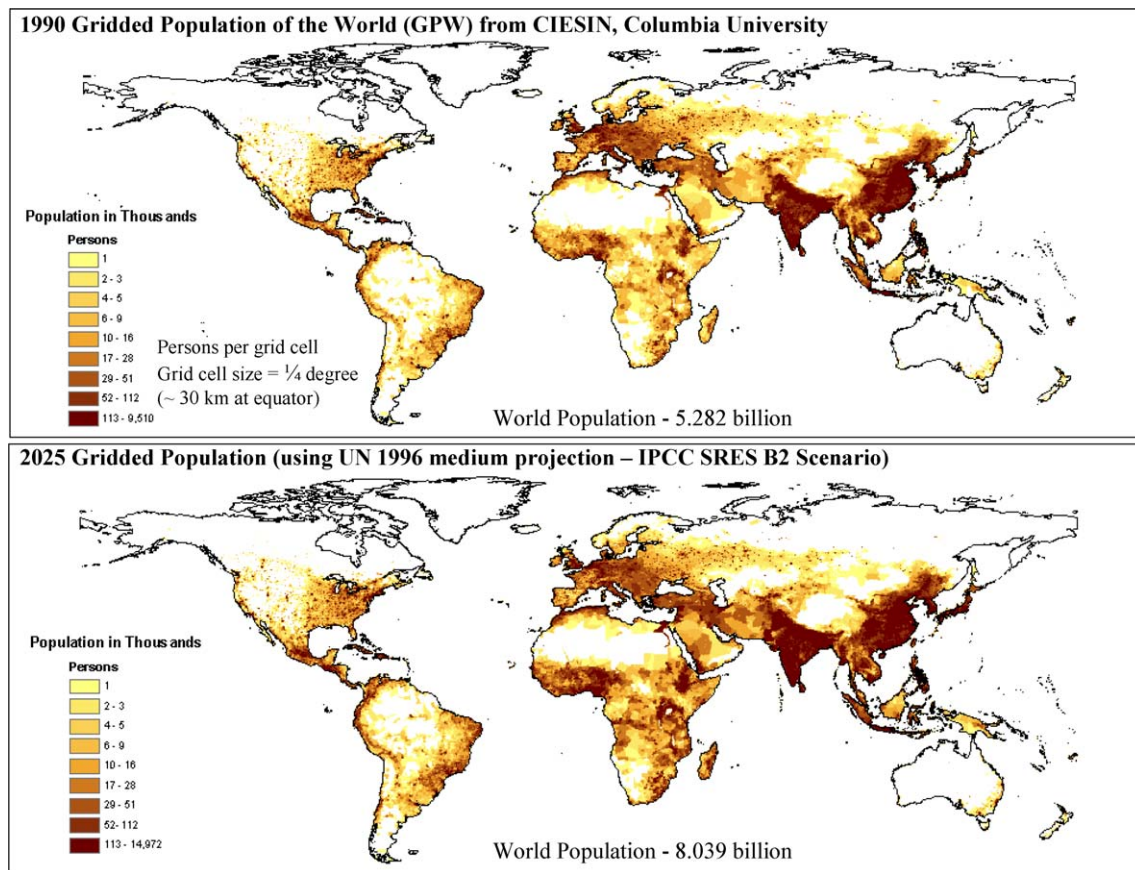


Fig. 1. (top) Gridded population of the world (GPW) in units of people/unit area (CIESIN et al., 2001). (bottom) A 2025 projection of GPW, using the IPCC SRES B2 population projection data available at the country level.

of international migration, the projection assumes that the regular flow will continue to 2025.

It is difficult to detect visual changes in Fig. 1 because areas of currently high population density will continue to have high densities in the near term. A clearer way to see changes in international population distribution is to show the change in population density between the two years (Fig. 2). The world population in 2025 is projected in this scenario to be 2.76 billion greater than in 1990. Although many of the current areas of high population density will continue to increase over the next two decades, other areas will experience declines, such as Eastern and parts of Western Europe, the former Soviet Union and Japan. This decline was alluded to in connection with GDP per capita changes in Europe and the former Soviet Union.

5.2. Description of GDP/unit area ("GDP density") map

A geo-spatial distribution of GDP per unit area (GDP "density"), closely related to the GPW map, has been developed by Sachs et al. (2001). The basic idea is to apply national and, where available, sub-national data on GDP per capita to GPW. GDP per capita can be

multiplied by population per unit area at each grid point of the GPW map. The resulting spatial indicator is then GDP per unit area, referred as GDP density.⁸

In the Sachs et al. (2001) study, gross national product (GNP) per capita was measured at standardized purchasing power parity (PPP), at both the national and sub-national level for 1995. To capture intra-country variance in income distribution, sub-national (first level state/province divisions or non-administrative regions) per capita GDP data were gathered for 19 of 152 countries in a geographic information system, including most of the large economies.

Since the downscaling presented within this paper has dealt firstly with MER-based GDP data, we have

⁸ An alternative approach for estimating the spatial distribution of economic activity involves use of the remote-sensed nocturnal lights distribution (Elvidge et al., 1997a, b). The intensity of nocturnal lighting has been shown to correlate well with a number of anthropogenic indicators such as population density, energy consumption, electricity consumption, CO₂ emissions, and GDP (Doll et al., 2000). The strength of the correlation varies among these indicators and within regions. By using the correlations, a GDP density map based on the distribution of nocturnal lighting has been developed (Sutton and Costanza, 2002).

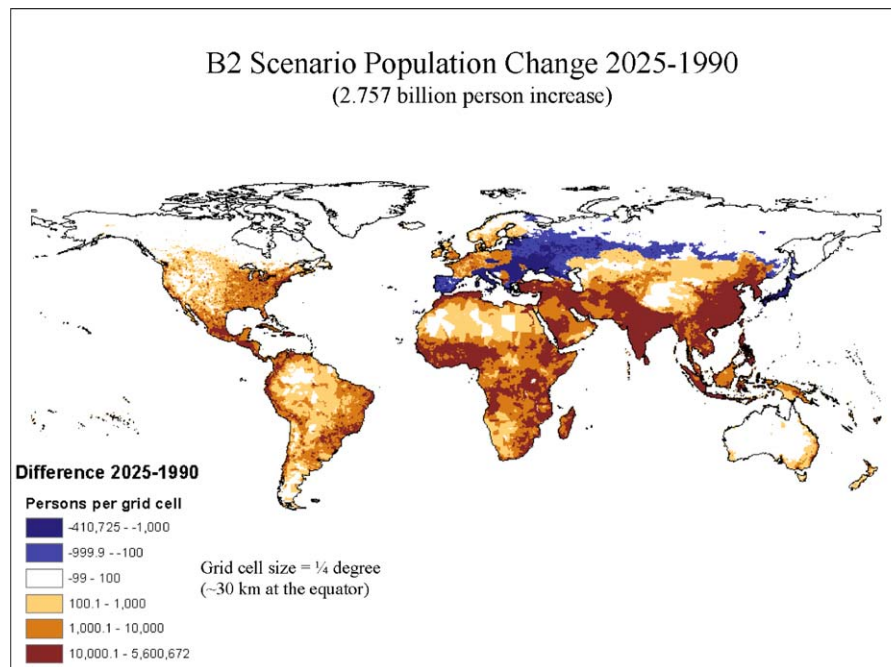


Fig. 2. Changes in the Gridded Population of the World (GPW) between the years 1990 and 2025, shown in Fig. 1. The figure highlights the major growth and decline areas of international population due to varying fertility, mortality and migration rates. Overall, there is a projected increase of world population of ~2.8 billion people. The distribution of these changes is far from uniform as evident in the map.

generated a market exchange rate version of the Sachs et al. (2001) GDP density map. We have also not yet applied sub-national GDP data to the map. Economic inequality within countries will not be accurately captured without such data, and inequality and related variations in access to resources are important determinants of vulnerability and adaptive capacity.

A 1990 GDP grid, shown at the top of Fig. 2, forms a baseline for our spatial GDP projections. We first used the 1990 country level population and GDP estimates to calculate 1990 per capita GDP. The map of GDP density is then calculated within a geographic information system by multiplying GDP per capita by the gridded population of the world. This multiplication converts the units of “GDP per capita” into GDP per unit area, because GPW is in units of population/unit area.

As with the 2025 population map, it is a straightforward exercise to generate a 2025 GDP density grid (Fig. 3, bottom). Note that *both* the projected 2025 population and GDP elements go into this grid. For the B2 GDP scenario, world GDP begins at ~21.7 trillion (1990) US\$ and increases to ~59 trillion (1990) US\$ by 2025. The visual changes in GDP density are somewhat clearer in this map than the population map, partly because the percentage increases in GDP are greater than for population. Particularly evident are the increases in GDP in Southern and South Eastern Asia, Sub Saharan Africa and Latin America.

It is anticipated that the population and GDP density grids are potentially useful data for analysts concerned with assessing ‘vulnerability’ and ‘adaptive capacity,’ as defined by the IPCC (2001), to future global and regional environmental changes and stresses. Broadly speaking, vulnerability indicators to climate change would likely include estimates of present or future populations at risk. Similarly, indicators for adaptive capacity may include an estimate of the state of development, or income, for those populations at risk. The high-resolution maps could assist detailed spatial studies of these indicators.

6. Conclusions

This paper has presented the development of a socio-economic database constructed based on the SRES report. A primary motivation for this work is to promote consistency between energy-econometric models that simulate greenhouse gas emissions, climate models that simulate the physical aspects of global climate change, and social sciences models that characterize the potential impacts on human welfare from global warming. The IPCC SRES report is a logical foundation for such a database because it represents a synthesis of the socio-economic and technological driving forces important for human impacts and the greenhouse emissions that may affect future climate. By developing the database, we sought to overcome a main

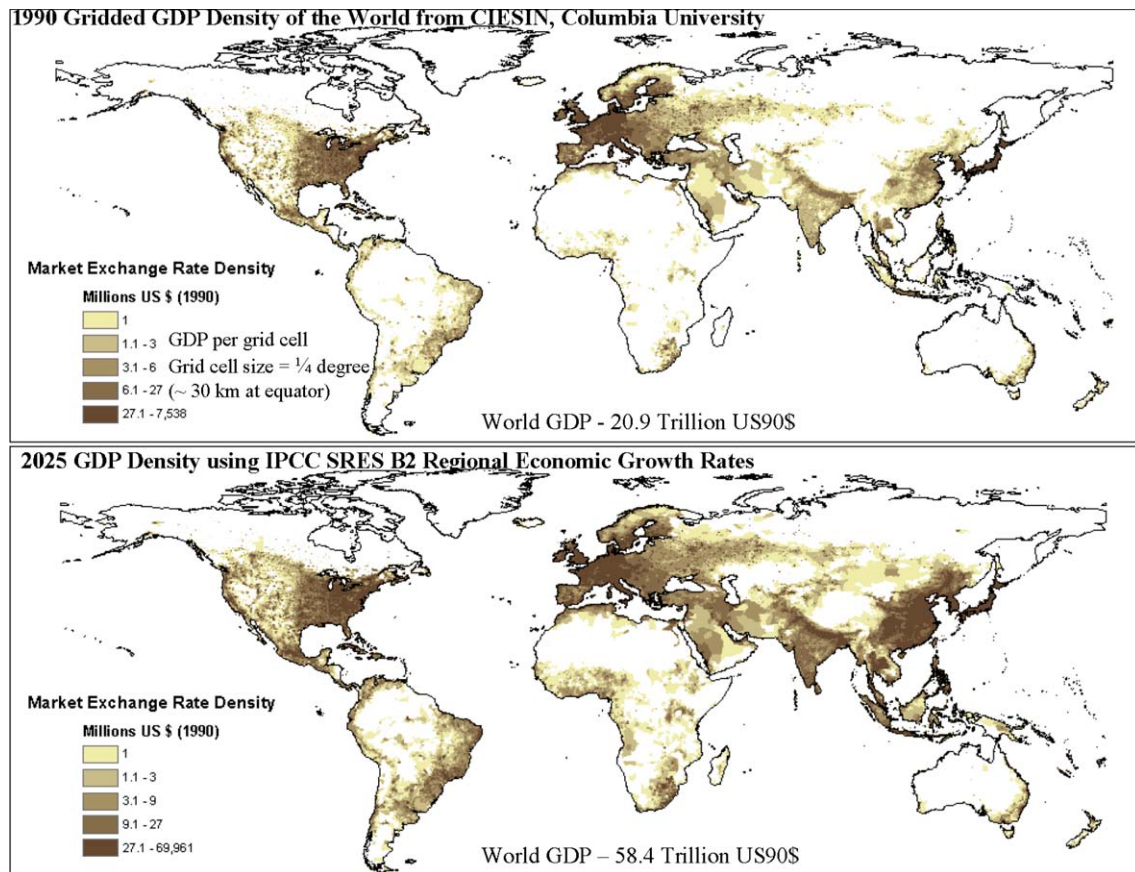


Fig. 3. (top) GDP/unit area map with GDP measured using traditional market exchange rate estimates. We projected the base year forward in time (bottom) using the country-level B2 scenario GDP and population downscaled data described in the first portions of this report.

obstacle of the SRES report for many human impacts studies, namely that the data presented therein exist in highly aggregated form, at a spatial scale too coarse for many local and regional analyses.

A number of problems emerged from the work. For the population downscaling, the main problem is the adoption of a uniform regional growth (or decline) rates after 2050, the end point of the UN country-level population projections. This introduced significant discontinuities in the population trend slopes for countries whose 2050 population growth rates differ significantly from the regional growth rates. Two potential alternative algorithms for downscaling involve using trend data of changing fractional shares of population size and growth rate. These may change the degree of the discontinuities and should be investigated.

Ideally, the best solution for population would be to adopt quality country-level projections to 2100, which are developed by some demographic research groups. However, in regard to SRES, neither the UN nor IIASA have, as yet, produced projections at the country level out to 2100.

With respect to the projected regional GDP data, three main problems have been identified: (1) The

downscaling methodology begins in 1995 and uses uniform regional growth rates from that point in time onward. As a result, current near-term differences in GDP growth rates between countries are not captured and our data readily show discrepancies with actual near-term country data. (2) For countries that have high 1990 GDP per capita values, and which also lie within developing regions with high anticipated GDP growth rates, 2100 GDP per capita can reach problematic high values. To project the GDP per capita for such countries will require more disaggregated treatments and probably relaxing the constraint for exact regional consistency with the SRES report. (3) The MER GDP data from the SRES marker models were used in the database for both the country-level and gridded values. For issues involving assessments of poverty and wealth, which are often important components of climate vulnerability and adaptation studies, national PPP data provide an alternative, and, in some cases, a more appropriate measure than traditional market-based GDP. The SRES did develop PPP trajectories, and downscaling these values would be an area for future database development.

Provision of socio-economic scenarios for use in global climate change studies at national and gridded

scales is a daunting challenge. To do the job carefully in a “bottom-up” approach, determining grid-by-grid or country-by-country values in a consistent manner would be an enormous task. On the other hand, the top-down approach, such as has been employed here, brings the types of methodological problems that we have presented in this paper. Answering this challenge calls for the development of multiple approaches and new methods, with clear recognition of the manifold uncertainties. We hope that the work presented here stimulates other researchers to take up and continue in this important task.

Acknowledgements

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Appendix A. Comparison of downscaling population with SRES regional totals

A1 population downscaling compared with SRES regional totals: The percent differences between the A1 downscaling and the SRES regional population totals are shown in Table 4(a). As with B2, the differences are very small, but in a few cases rise to 1–2%. As noted above, the marker model for the A1 scenario (AIM; Table 2) has a different regional disaggregation than the IIASA population projection. In adapting the IIASA population totals to the AIM model, small differences in

population from the original IIASA data probably were introduced.

B1 Population downscaling compared with SRES regional totals: The B1 population downscaling regional sums (Table 4(c)) show reasonable agreement with the SRES marker model (IMAGE from RIVM). It should be noted for this projection that IMAGE placed Turkey and Cyprus in the Middle East region, as opposed to OECD, as is typical with the other SRES marker models. When calculating the regional sums for B1, we therefore placed Turkey and Cyprus in the Middle East. For all the other population projections, it was placed in OECD. The marker model for the B1 scenario (IMAGE; Table 2) has a different regional disaggregation than the IIASA population projection. In adapting the IIASA population projections to the RIVM model, small differences in population may have been introduced.

A2 Population downscaling compared with SRES regional totals: The A2 population downscaling again compares generally well (Table 4(b)), but with some isolated years of discrepancies of 5–6%. This again is probably due to small differences introduced by the marker model in this case (ASF, Table 2), when it adapted the IIASA regional population projections to the different ASF model regions. In addition, the ASF model computed results in 25-year intervals so the errors shown may also be due to interpolation factors specific to the model.

B2 Population downscaling compared with SRES regional totals: In Table 4(d) we show the result of re-aggregating our downscaled B2 population estimates from the above website, and then comparing these sums to the aggregated totals in the SRES report. As seen, the differences are extremely small, if not zero, and apart from the base year, are on the order of less than 0.1%. The slightly larger base year differences (<0.5%) are due to the fact that 1990 is not the base year for the 1998 UN Long Range projection used in the SRES report—which is 1995. As indicated above, we accessed 1990 country-level population data from a recent UN Common Statistics database at: <http://unstats.un.org/> in April 2002. The SRES report had to similarly use an independent 1990 source for population so that source evidently had small differences with our accessed data.

Appendix B. Comparison of the SRES regional GDP totals with the downscaled GDP data regional totals

A1 GDP downscaling compared with SRES regional totals: Table 5(a) presents results for the SRES A1 scenario. We use the regional economic growth rates from the Asian Pacific Integrated Model (AIM)—the marker model for the A1 scenario in general.

Table 4

(a–d) Comparison of regional population totals from SRES report with summed downscaled data

SRES Regions	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
<i>(a) A1 comparison</i>												
<i>Downscaled projection A1/B1 POP data (in millions)</i>												
OECD90	863	919	965	1006	1043	1069	1081	1084	1089	1098	1108	1109
ASIA	2807	3260	3620	3936	4147	4238	4219	4084	3867	3589	3258	2882
REF	412	419	427	433	435	433	423	409	392	374	357	339
ALM	1200	1519	1875	2240	2557	2790	2979	3089	3115	3064	2934	2726
TOTAL	5282	6117	6887	7616	8182	8530	8702	8666	8462	8125	7657	7055
<i>SRES A1B-AIM marker scenario data (in millions)</i>												
OECD90	859	919	960	1002	1043	1062	1081	1086	1091	1097	1103	1110
ASIA	2798	3261	3556	3851	4147	4183	4220	4016	3822	3541	3194	2882
REF	413	419	424	430	435	429	423	406	391	374	356	339
ALM	1192	1519	1865	2211	2557	2761	2980	3024	3067	3013	2866	2727
World	5262	6117	6805	7493	8182	8439	8704	8538	8375	8030	7528	7056
<i>% Difference</i>												
OECD90	0.52	0.00	0.52	0.43	0.00	0.69	−0.02	−0.16	−0.22	0.10	0.42	−0.05
ASIA	0.32	−0.02	1.80	2.21	0.01	1.32	−0.02	1.70	1.17	1.35	2.01	−0.01
REF	−0.29	−0.07	0.75	0.79	−0.03	0.89	−0.06	0.62	0.27	0.10	0.41	−0.08
ALM	0.64	−0.03	0.53	1.30	−0.02	1.03	−0.02	2.14	1.56	1.68	2.36	−0.05
TOTAL	0.38	−0.01	1.20	1.64	0.00	1.08	−0.02	1.49	1.04	1.18	1.71	−0.01
<i>(b) A2 comparison</i>												
<i>Downscaled projection A2 POP data (in millions)</i>												
OECD90	863	923	982	1030	1076	1117	1152	1193	1250	1320	1402	1496
ASIA	2807	3295	3803	4308	4816	5314	5763	6188	6575	6897	7145	7339
REF	412	421	440	455	472	495	519	549	584	623	663	706
ALM	1200	1530	1943	2398	2882	3372	3861	4321	4731	5063	5313	5525
TOTAL	5282	6170	7167	8191	9246	10298	11295	12252	13140	13903	14524	15067
<i>SRES A2-ASF marker scenario POP data (in millions)</i>												
OECD90	851	923	975	1027	1072	1131	1151	1202	1228	1323	1451	1496
ASIA	2791	3295	3801	4308	4779	5500	5764	6137	6333	6858	7214	7340
REF	418	421	438	454	473	507	519	551	568	622	684	706
ALM	1222	1530	1974	2417	2846	3578	3862	4250	4458	5025	5394	5526
World	5282	6170	7188	8206	9170	10715	11296	12139	12587	13828	14743	15068
<i>% Difference</i>												
OECD90	1.48	0.03	0.68	0.29	0.36	−1.25	0.04	−0.71	1.77	−0.26	−3.35	0.03
ASIA	0.57	0.01	0.04	−0.01	0.77	−3.38	−0.01	0.83	3.82	0.57	−0.96	−0.01
REF	−1.49	0.09	0.43	0.25	−0.16	−2.37	−0.09	−0.41	2.85	0.12	−3.00	−0.01
ALM	−1.83	0.00	−1.57	−0.80	1.27	−5.74	−0.02	1.68	6.13	0.76	−1.49	−0.02
TOTAL	0.00	0.00	−0.29	−0.19	0.83	−3.89	−0.01	0.93	4.40	0.54	−1.48	−0.01
<i>(c) B1 comparison</i>												
<i>Downscaled projection A1/B1 POP data (in millions)</i>												
OECD90	807	851	888	920	949	968	975	981	989	1000	1012	1015
ASIA	2807	3260	3620	3936	4147	4238	4219	4084	3867	3589	3258	2882
REF	412	419	427	433	435	433	423	409	392	374	357	339
ALM	1256	1586	1952	2326	2651	2890	3085	3192	3215	3161	3030	2820
TOTAL	5282	6117	6887	7616	8182	8530	8702	8666	8462	8125	7657	7055
<i>SRES B1 IMAGE marker scenario POP data (in millions)</i>												
OECD90	799	849	890	932	965	990	1001	1005	1009	1020	1029	1032
ASIA	2781	3246	3609	3929	4142	4235	4220	4088	3871	3594	3262	2886
REF	412	429	437	443	445	443	432	419	401	384	365	347
ALM	1287	1597	1954	2315	2643	2879	3055	3159	3202	3145	3006	2783
World	5280	6122	6892	7618	8196	8547	8708	8671	8484	8142	7663	7047
<i>% Difference</i>												
OECD90	0.95	0.28	−0.22	−1.25	−1.68	−2.18	−2.63	−2.34	−2.01	−1.91	−1.67	−1.62
ASIA	0.94	0.44	0.30	0.18	0.13	0.08	−0.02	−0.09	−0.11	−0.15	−0.12	−0.15

Table 4 (continued)

SRES Regions	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
REF	−0.05	−2.40	−2.25	−2.17	−2.28	−2.29	−2.15	−2.50	−2.23	−2.51	−2.07	−2.38
ALM	−2.37	−0.68	−0.11	0.47	0.29	0.40	1.00	−1.03	−0.40	0.52	−0.78	1.32
TOTAL	0.04	−0.09	−0.07	−0.03	−0.17	−0.20	−0.07	−0.06	−0.26	−0.21	−0.08	0.12
(d) B2 comparison												
<i>Downscaled projection B2 POP data (in millions)</i>												
OECD90	863	916	952	981	993	987	975	964	950	940	933	927
ASIA	2788	3248	3648	4007	4311	4537	4695	4788	4855	4902	4938	4969
REF	412	415	417	418	416	411	406	396	389	384	381	379
ALM	1188	1510	1871	2262	2648	2990	3287	3552	3762	3929	4051	4137
TOTAL	5251	6089	6888	7669	8368	8926	9363	9700	9956	10155	10303	10412
<i>SRES B2 MESSAGE marker scenario POP data (in millions)</i>												
OECD90	659	916	953	982	994	988	976	965	951	941	934	928
ASIA	2798	3248	3649	4008	4312	4538	4696	4790	4856	4901.51	4938.07	4968
REF	413	415	417.099	418.066	415.728	411.176	405.953	395.856	388.687	384.064	381.041	379.025
ALM	1192	1511	1872	2263	2649	2992	3289	3554	3764	3931	4053	4139
World	5262	6091	6891	7672	8372	8930	9367	9704	9960	10158	10306	10414
<i>% Difference</i>												
OECD90	052	−0.02	−0.08	−0.06	−0.06	−0.06	−0.07	−0.10	−0.05	−0.09	−0.10	−0.10
ASIA	−0.36	−0.01	−0.03	−0.02	−0.02	−0.03	−0.03	−0.04	−0.03	0.00	0.00	0.03
REF	−0.33	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ALM	−0.31	−0.07	−0.07	−0.05	−0.04	−0.05	−0.07	−0.07	−0.06	−0.05	−0.05	−0.05
TOTAL	−0.20	−0.03	−0.04	−0.04	−0.05	−0.05	−0.05	−0.04	−0.04	−0.03	−0.03	−0.02

Note: Cyprus and Turkey are listed in the region of Middle East with IMAGE model which was used for the B1 marker scenario.

As can be seen from Table 5(a), for the base year 1990, the country level data we have downloaded from the UN and World Bank sources shows some regional differences from the estimates used by AIM modeling team in the SRES report. The discrepancy is greatest for the REF region at 7.24%. (The 7.24% base year difference is exactly maintained throughout the projection period because the REF region happens to be a single model region in the AIM model (Table 2).) The other regions show smaller differences. Unlike REF, these differences are not constant over the projection period because these regions comprise more than one AIM model region and the changing weights of the model regions affect the overall SRES reporting region differences. Generally, the agreement shown is characteristic of the data available at this time and we deem it acceptable for an initial version of the database.

A2 GDP downscaling compared with SRES regional totals: Table 5(b) presents regional totals for our GDP downscaled projections for the A2 scenario using regional economic growth rates from the Atmospheric Stabilization Framework (ASF) model from ICF Consulting in the USA—the marker model for the A2 scenario.

As seen in Table 5(b), there are significant differences between the summed base year GDP values for the REF, OECD90 and ALM regions from the A2 marker model as compared to the country data available currently from the UN and World Bank sources. Most

of these discrepancies, however, can be explained by the fact that the A2 marker model had significantly different regional estimates for 1990 GDP for REF, OECD90 and ALM, when compared to other marker models in the SRES report. For example, the ASF model estimate for A2's 1990 REF GDP is ~13% lower than the B2 1990 REF GDP used in the MESSAGE marker run. Similarly, the ASF model estimate for A2's 1990 OECD GDP is ~6% lower than the B2 1990 OECD GDP from the MESSAGE marker. Finally, the ASF model estimate for A2 1990 ALM GDP is ~26% higher than the B2 1990 ALM GDP for the MESSAGE marker. These differences, combined with the additional, smaller, differences between our summed country list and the MESSAGE marker sums, explain the overall discrepancies seen for A2, and the linear downscaling procedure simply preserves these differences over the projection period. More importantly, these differences imply that a single base year country GDP list cannot be made consistent with all the SRES marker models. The SRES report did not require exact harmonization at the regional level for GDP between the marker models.

A remedy for our database would be to develop a second base year GDP country list that is more consistent with the ASF model assumptions. However, presenting model-specific base year country lists is potentially confusing and difficult to justify for users, and we have decided to leave the current numbers as they stand.

Table 5

(a–d) Comparison of regional GDP totals from SRES report with summed downscaled GDP data

SRES Regions	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
(a) A1 GDP comparison												
<i>Downscaled projection A1 GDP data (MER, Trillion US\$)</i>												
OECD90	17.1040	21.4640	26.4321	32.4735	39.8031	48.2510	56.6989	68.6425	80.5861	94.6469	110.8248	127.0028
ASIA	1.4813	2.6023	5.5091	11.6030	24.4137	41.5816	58.7495	87.4491	116.1486	144.4130	172.2421	200.0711
REF	1.1593	0.8917	1.6539	3.0661	5.6827	9.4832	13.2836	17.3846	21.4856	26.1613	31.4117	36.6621
ALM	2.0282	2.8076	5.6135	10.9148	20.8210	36.9344	53.0477	73.4670	93.8863	115.0903	137.0789	159.0676
Total	21.7728	27.7657	39.2087	58.0574	90.7205	136.2501	181.7797	246.9432	312.1066	380.3114	451.5575	522.8037
<i>SRES A1-AIM marker scenario (modeler's) GDP data (MER, Trillion US\$)</i>												
OECD90	16.3560	20.5188	25.2619	31.0287	38.0241	46.0852	54.1464	85.5330	76.9195	90.3198	105.7338	121.1477
ASIA	1.5071	2.7099	5.7877	12.3116	26.1897	44.4681	62.7465	91.8976	121.0487	149.9520	178.6075	207.2630
REF	1.0810	0.8315	1.5422	2.8590	5.2989	8.8427	12.3865	16.2105	20.0345	24.3945	29.2903	34.1861
ALM	1.9240	2.6647	5.3072	10.2809	19.5466	35.7943	52.0420	73.9372	95.8324	118.6097	142.2692	165.9287
World	20.8681	26.7249	37.8989	56.4803	89.0593	135.1903	181.3213	247.5782	313.8352	383.2760	455.9008	528.5256
<i>% Difference</i>												
OECD90	4.57	4.61	4.63	4.66	4.68	4.70	4.71	4.75	4.77	4.79	4.81	4.83
ASIA	−1.71	−3.97	−4.81	−5.76	−6.78	−6.49	−6.37	−4.84	−4.05	−3.69	−3.56	−3.47
REF	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24	7.24
ALM	5.41	5.36	5.77	6.17	6.52	3.19	1.93	−0.64	−2.03	−2.97	−3.65	−4.13
TOTAL	4.34	3.89	3.46	2.79	1.87	0.78	0.25	−0.26	−0.55	−0.77	−0.95	−1.08
(b) A2 GDP comparison												
<i>Downscaled projection A2 GDP data (MER, Trillion US\$)</i>												
OECD90	17.1040	20.9017	24.9384	29.0258	33.9276	39.2717	44.6157	52.7849	60.9540	71.6462	84.8613	98.0764
ASIA	1.4813	2.3602	3.6517	5.4996	8.4197	11.9448	15.4700	22.0608	28.6515	37.4270	48.3874	59.3477
REF	1.1593	1.0020	1.2760	1.7520	2.6610	3.6058	4.5506	6.4089	8.2671	10.8545	14.1711	17.4876
ALM	2.0282	2.8771	4.2394	6.4816	10.2356	14.6411	19.0466	27.0401	35.0336	45.2163	57.5882	69.9600
Total	21.7728	27.1410	34.1055	42.7590	55.2439	69.4634	83.6829	108.2946	132.9062	165.1440	205.0079	244.8717
<i>SRES A2-ASF marker scenario (modeler's) GDP data (MER, Trillion US\$)</i>												
OECD90	15.3074	18.7008	22.3072	25.9627	30.3426	35.1154	39.8882	47.1755	54.4629	63.9997	75.7860	87.5723
ASIA	1.4369	2.2842	3.5299	5.3149	8.1392	11.5472	14.9552	21.3089	27.6625	36.0990	46.6184	57.1378
REF	0.9444	0.8163	1.0395	1.4273	2.1678	2.9375	3.7073	5.2211	6.7350	8.8428	11.5448	14.2467
ALM	2.3915	3.4254	5.0549	7.7979	12.3231	17.6694	23.0157	32.6530	42.2903	54.4524	69.1394	83.8264
World	20.0802	25.2267	31.9315	40.5028	52.9726	67.2695	81.5663	106.3585	131.1506	163.3940	203.0886	242.7831
<i>% Difference</i>												
OECD90	11.74	11.77	11.80	11.80	11.82	11.84	11.85	11.89	11.92	11.95	11.97	11.99
ASIA	3.09	3.33	3.45	3.48	3.45	3.44	3.44	3.53	3.58	3.68	3.79	3.87
REF	22.75	22.75	22.75	22.75	22.75	22.75	22.75	22.75	22.75	22.75	22.75	22.75
ALM	−15.19	−16.01	−16.13	−16.88	−16.94	−17.14	−17.25	−17.19	−17.16	−16.96	−16.71	−16.54
TOTAL	8.43	7.59	6.81	5.57	4.29	3.26	2.59	1.82	1.34	1.07	0.95	0.86
(c) B1 GDP comparison												
<i>Downscaled projection B1 GDP data (MER, Trillion US\$)</i>												
OECD90	16.9279	20.7608	26.5964	33.1906	39.2226	45.0478	51.1830	56.8787	61.4385	68.1196	75.9150	84.6249
ASIA	1.4705	2.8157	5.0042	9.0169	15.7734	26.0720	39.7435	53.9853	67.9828	82.4386	95.9732	107.6460
REF	1.1593	0.8560	1.2146	2.0402	3.3219	5.1284	7.3843	9.7544	12.2876	15.2612	18.3604	21.6351
ALM	2.2151	3.2424	5.8453	10.4091	18.1218	29.8205	45.4078	62.2924	81.4470	102.3360	121.9780	140.0354
Total	21.7728	27.6750	38.6605	54.6568	76.4397	106.0688	143.7186	182.9109	223.1558	268.1554	312.2266	353.9413
<i>SRES B1-IMAGE marker scenario (modeler's) GDP data (MER, Trillion US\$)</i>												
OECD90	16.5114	20.2455	25.9367	32.3587	38.2350	43.9071	49.8650	55.3942	59.8155	66.2919	73.8509	82.2958
ASIA	1.4162	2.7183	4.8225	8.6688	15.1223	24.9229	37.8977	51.4211	64.7796	78.6689	91.7481	103.0996
REF	0.9710	0.7188	1.0203	1.7127	2.7867	4.2995	6.1874	8.1705	10.2907	12.7792	15.3725	18.1131
ALM	2.1018	3.0870	5.5513	9.8220	16.9351	27.5782	41.6207	56.7132	73.6254	91.9668	109.1302	124.8637
World	21.0004	26.7696	37.3308	52.5623	73.0790	100.7078	135.5707	171.6990	208.5111	249.7068	290.1017	328.3721
<i>% Difference</i>												
OECD90	2.52	2.55	2.54	2.57	2.58	2.60	2.64	2.68	2.71	2.76	2.79	2.83
ASIA	3.83	3.58	3.77	4.02	4.31	4.61	4.87	4.99	4.94	4.79	4.61	4.41

Table 5 (continued)

SRES Regions	1990	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
REF	19.40	19.08	19.05	19.12	19.21	19.28	19.34	19.39	19.41	19.42	19.44	19.44
ALM	5.39	5.04	5.30	5.98	7.01	8.13	9.10	9.84	10.62	11.27	11.77	12.15
TOTAL	3.68	3.38	3.56	3.98	4.60	5.32	6.01	6.53	7.02	7.39	7.63	7.79
(d) B2 GDP comparison												
<i>Downscaled projection B2 GDP data (MER, Trillion US\$)</i>												
OECD90	17.1040	22.0905	27.7183	31.7168	34.6355	37.4632	40.0675	42.8028	46.5286	50.2717	54.5569	59.4365
ASIA	1.4813	3.3629	6.9427	12.7347	20.6456	29.9670	41.0703	52.1263	63.5545	74.5230	85.3287	96.6042
REF	1.1593	1.0282	1.3093	1.8808	2.9972	4.7803	7.0117	9.1940	11.2188	12.7930	14.1800	15.4808
ALM	2.0282	2.8756	3.8985	5.7510	9.2786	15.3882	24.2027	34.6644	45.2724	54.7490	63.1150	71.1513
Total	21.7728	29.3573	39.8688	52.0833	67.5569	87.5987	112.3523	138.7875	166.5743	192.3366	217.1806	242.6728
<i>SRES B2 MESSAGE marker scenario (modeler's) GDP data (MER, Trillion US\$)</i>												
OECD90	16.3557	21.1213	26.4913	30.3074	33.0925	35.7906	38.2759	40.8672	44.3946	47.9321	51.9785	56.5847
ASIA	1.5068	3.4795	7.2111	13.2140	21.3212	30.7225	41.7993	52.7400	64.0829	74.9872	85.7696	97.0571
REF	1.0811	0.9646	1.2309	1.7660	2.8097	4.4744	6.5552	8.5883	10.4777	11.9480	13.2466	14.4674
ALM	1.9228	2.7274	3.6963	5.4522	8.7899	14.5506	22.8323	32.6378	42.5629	51.4248	59.2568	66.7843
World	20.8663	28.2929	38.6296	50.7397	66.0133	85.5382	109.4628	134.8332	161.5181	186.2921	210.2515	234.8936
<i>% Difference</i>												
OECD90	4.58	4.59	4.63	4.65	4.66	4.67	4.68	4.74	4.81	4.88	4.96	5.04
ASIA	−1.69	−3.35	−3.72	−3.63	−3.17	−2.46	−1.74	−1.16	−0.82	−0.62	−0.51	−0.47
REF	7.24	6.59	6.37	6.50	6.67	6.84	6.96	7.05	7.07	7.07	7.05	7.00

Note: The regional sum discrepancies seen here are discussed in the data description.

B1 GDP downscaling compared with SRES regional totals: Table 5(c) presents regional downscaled totals for the B1 scenario using regional economic growth rates from the Integrated Model to Assess the Greenhouse Effect (IMAGE) from RIVM in the Netherlands—the marker model for the B1 scenario.

As seen in Table 5(c), the regional sums for the data differ significantly in the REF region. This initial discrepancy is essentially maintained throughout the downscaling period. The main cause for this discrepancy is similar to the discrepancies explained for the scenario A2 above—the marker model for B1 had a large difference in the 1990 GDP estimate for REF compared to the 1990 REF GDP estimate for the marker models for the other scenarios. Specifically, the B1 marker 1990 REF GDP is ~10% lower than the B2 marker 1990 REF GDP. The remainder of the discrepancy for the B1 REF GDP relates to the smaller base year GDP differences between our country list and the general SRES marker regional sums.

Once again, this shows that a single country-level base year GDP list cannot be consistent with all the base year marker model regional GDP estimates.

B2 GDP downscaling compared with SRES regional totals: Table 5(d) presents regional comparisons for the SRES B2 scenario. We used the regional economic growth rates from the IIASA MESSAGE model—the marker model for the B2 scenario in general.

Table 5(d) shows that the regionally summed GDP values compare fairly well with the regional sums in the SRES book report. The base year differences are a

maximum of about 7% for the REF region and lower for the other regions. These base year differences are largely preserved throughout the projection period with small fluctuations due to changing B2 model regional weights.

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